Chapter 9
Conducting GPS Field Surveys

9-1. General

This chapter presents guidance to field personnel performing GPS surveys for typical USACE military construction and civil works projects. The primary emphasis in this chapter is on performing static and kinematic carrier phase differential GPS measurements. Absolute and differential code phase GPS positioning and mapping techniques are also covered. Detailed field instructions for specific GPS receivers are typically contained in the operating or reference manuals provided by the manufacturer. Given the wide variety of GPS receivers, coupled with the different types of data collection, logging, processing, and adjustment techniques that can be performed in the field, this chapter can only provide a brief overview of some representative systems; and highlight observing criteria which is common to all types of GPS equipment.

9-2. General GPS Field Survey Procedures

The following are some general GPS field survey procedures that should be performed at each occupied point on a GPS survey. These general procedures apply to either static or kinematic observation methods, and to either real-time or post-processed data collection.

a. Receiver set up. GPS receivers shall be set up in accordance with manufacturer's specifications prior to beginning any observations. Base station antennas are typically mounted on a tripod and kinematic rover receivers and antenna are mounted on fixed-height range poles. If real-time kinematic observations are being collected, then radio or satellite communication links will need to be set up. Newer GPS systems contain a separate data controller to record, coordinate, and process all GPS data collection. Figure 9-1 depicts a typical data collector.

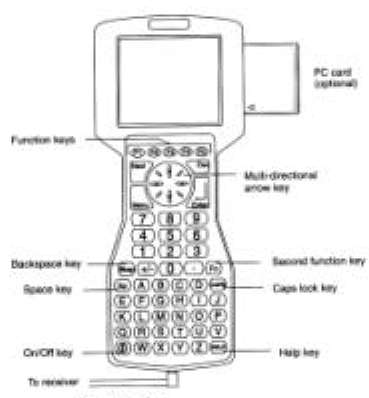

Figure 9-1. Typical GPS data collector used for static and real-time kinematic surveys (Trimble Survey Controller, Trimble Navigation LTD)

b. Antenna setup. All tribrachs used on a project should be calibrated and adjusted prior to beginning each project. Dual use of both optical plummets and standard plumb bobs is strongly recommended since centering errors represent a major error source in all survey work, not just GPS surveying. A reference line marked on the antenna should always be pointed or aligned in the same direction (e.g., north), using a magnetic compass. Tripods should be checked daily for tightness and fixed-height tripods and range poles should be periodically calibrated.

c. Height of instrument measurements. Height of instrument (HI) refers to the correct measurement of the distance of the GPS antenna above the reference monument over which it has been placed. In actuality, the physical measurement is made to some fixed point on the antenna mounting device from which the previously calibrated distance to the antenna phase center (APC) can be added. This is shown for different types of fixed range pole mounts in Figure 9-2. HI measurements should be made both before and after each observation session. The standard reference points for each antenna will be established prior to the beginning of the observations so all observers will be measuring to the same point. All HI measurements will be made in both meters and feet for redundancy and blunder detection. HI measurements shall be determined to the nearest millimeter in metric units and to the nearest 0.01 ft (or 1/16 in.). It should be noted whether the HI is vertical or diagonal. Each GPS receiver/antenna manufacturer provides specific antenna height measuring guidance in their instrument operating manual. Figure 9-2 depicts some of the measurement methods required for different types of Trimble antennas. For some instruments (e.g., Trimble GPS Total Station 4800 and 4600LS Receiver) a special measuring tape and instructions is provided by the manufacturer--see lower right example in Figure 9-2. When a ground plane is used at a base receiver, direct distances are measured to different points on the antenna and the average of these distances is entered into the controller as a slope distance for automatic correction. The GPS survey controller will typically query input for the type of antenna and mount.

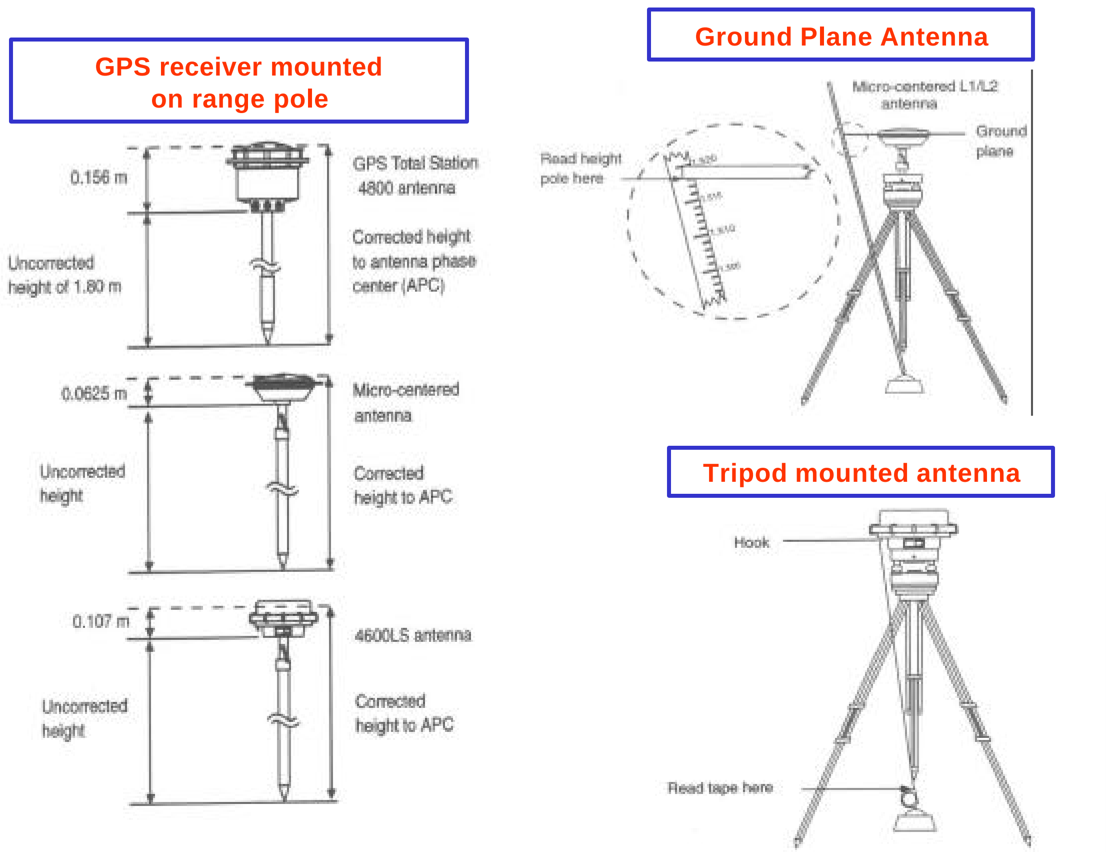

Figure 9-2. Antenna height measurements for various types of mounts and antenna types (Trimble Navigation LTD)

d. Field GPS observation recording procedures. Field recording books, log sheets, log forms, or full-text input data collectors will be completed for each station and/or session. Any acceptable recording media may be used. For archiving purposes, standard bound field survey books are preferred; however, USACE commands may specify written or automated logging media to be used in lieu of a survey book. The amount of record keeping detail will be project dependent; low-order topographic mapping points need not have as much descriptive information as would permanently marked primary control points. The following typical data may be included on these field logging records:

(1) Project, construction contract, observer(s) name(s), and/or A-E or construction contractor firm and contract/task order number

(2) Station designation

(3) Station file number

(4) Date, weather conditions, etc.

(5) Time start/stop session (local and UTC)

(6) Receiver, antenna, data recording unit, and tribrach make, model, and serial numbers

(7) Antenna height: vertical or diagonal measures in inches (or feet) and meters (or centimeters)

(8) Space vehicle (SV) designations of satellites observed during sessions

(9) Sketch of station location

(10) Approximate geodetic location and elevation

(11) Problems encountered

USACE commands may require that additional data be recorded. These will be contained in individual project instructions or contract task order scopes. Samples of typical GPS recording forms are shown later in this section.

e. Field calibrations and initializations. When kinematic surveys are performed, it may be necessary to calibrate the base station to a known local coordinate point and reference datum. An initialization process may also be required for some types of kinematic surveys. Check with manufacturer's recommendations on specific techniques for calibrating RTK surveys to a local datum. These calibrations should be clearly noted on log records for the survey.

f. Field processing and verification. It is strongly recommended that GPS data processing and verification be performed in the field where applicable. This is to identify any problems that can be corrected before returning from the field. Survey processing and verification are covered in Chapters 10 and 11.

g. Session designations. A survey session in GPS terminology refers to a single period of observations. Sessions and station designations are usually denoted and input into the data collector using alphanumeric characters, following format restrictions allowed by the receiver vendor. The station and session designations should be clearly correlated with entries on the log forms so that there are no questions during subsequent baseline processing. The date of each survey session should be recorded during the survey as calendar dates and Julian days and used in the station/session designation. Some GPS software programs will require Julian dates for correct software operation. In addition to determination of station/session designations before the survey begins, the crew chief may need to consider or review some of the following factors:

- Persons designated to occupy each station.

- Satellite visibility for each station.

- Site reconnaissance data for stations to be occupied. Remember the same person who performed the initial site reconnaissance may not be the individual performing the survey; therefore, previous site reconnaissance data may require clarification before survey commencement.

- Project sketch.

- Explicit instructions on when each session is to begin and end, and follow-up sessions.

- Providing observers with data logging sheets for each occupied station.

h. GPS Station Log forms. The following figures contain samples of station logs used by various USACE districts. Standard bound field survey books may be used in lieu of separate log/work sheets.

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

PROJECT NAME COYOTE DAM LOCALITY UKIAH, CA
OBSERVER LARRY LAMB AGENCY/FIRM COE, SACRAMENTO DIST.
RECEIVER TRIMBLE 4000 SL S/N 2820A00223
ANTENNA TRIMBLE MICRO SL S/N 2816A00224
DATA RECORDING UNIT RECEIVER S/N 2820A00223
TRIBRACH WILD GDF22 S/N N/A LAST CALIBRATED: 4/24/89

	SESSION 1	SESSION 2	SESSION 3
STATION NAME	PIER 2	PIER 2	PIER 2
STATION NUMBER	2002	2002	2002
DAY OF YEAR	115	115	115
DATE MM DD YY	04/25/89	04/25/89	04/25/89
UTC TIME OF OBSERVATION	START 04:56 STOP 05:55	START 06:10 STOP 07:38	START 07:55 STOP 09:20

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	0.120 0.120 0.119 4 12/16 IN = 0.121 M MN = 0.120 M	0.116 0.116 0.116 4 9/16 IN = 0.116 M MN = 0.116 M	0.123 0.124 0.124 4 14/16 IN = 0.124 M MN = 0.1238 M
SLOPE @ END	4 11/16 4 12/16 4 11/16 0.120 M = 4 12/16 IN MN = 0.120 M	4 9/16 4 9/16 4 9/16 0.116 M = 4 9/16 IN MN = 0.116 M	4 13/16 4 14/16 4 14/16 0.123 M = 4 14/16 IN MN = 0.1230 M
MN ADJ TO VERT	0.120 M	0.116 M	0.1234 M

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	39-12-30	39-12-22.64	39-12-30	39-12-22.48	39-12-30	39-12-22.81
LONG	123-10-30	123-10-33.42	123-10-30	123-10-33.20	123-10-30	123-10-33.67
HT	244.0	210.6	244.0	199.8	244.0	222.8
PDOP	3.6		4.8		4.0	
SVS TO TRACK	02, 03, 06, 09, 11, 12, 13, 14		02, 03, 06, 09, 11, 12, 13, 14		03, 06, 09, 11, 12, 13, 14, 16	

LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	21:55	21:56	23:38	23:10	01:20	00:55
STOP	22:55	22:55	00:38	00:38	02:20	02:20

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Figure 9-3. Sample USACE GPS data logging sheet

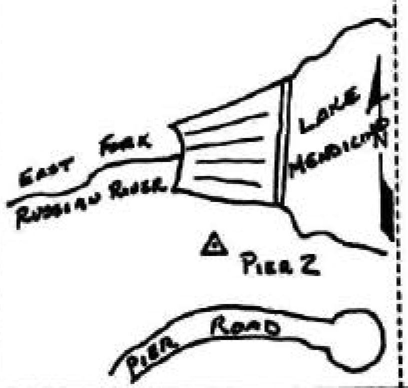
U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

****

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	100 ft	100 ft	35 ft
POWER SUPPLY	12v DC	12v DC	12v DC
WEATHER CONDITIONS	Clear, Cool 45°	Clear, Cool 40°	Clear, Breezy 40°
MONUMENT TYPE	"C" (Set in Pier)	← Same	Same
EXACT STAMPING	Pier 2 1953	← "	"
AGENCY CAST IN DISK	COE	← "	"

****

SKETCH OF SITE

SESSION 1	SESSION 2	SESSION 3
	Same ← N	Same ← N

****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurance and duration.

The Antenna Was Mounted Directly over Pier 2 with No Tripod used.

Antenna Height was Measured Vertically From Ground Plane To Brass Disk.

****

PAGE 2

Figure 9-3. (Concluded)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

****

PROJECT NAME ____________________ LOCALITY ____________
OBSERVER ______________ AGENCY/FIRM ______________
RECEIVER ______________________ S/N ______________
ANTENNA ______________________ S/N ______________
DATA RECORDING UNIT ____________ S/N ______________
TRIBRACH ____________ S/N ______ LAST CALIBRATED: ______

****

	SESSION 1		SESSION 2		SESSION 3	
STATION: NAME	________		________		________	
NUMBER	________		________		________	
DAY OF YEAR	________		________		________	
DATE MM DD YY	________		________		________	
UTC TIME OF OBSERVATION	START	STOP	START	STOP	START	STOP

****

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	___ ___ ___ ___IN=___ M MN = ______ M	___ ___ ___ ___IN=___ M MN = ______ M	___ ___ ___ ___IN=___ M MN = ______ M
SLOPE @ END	___ ___ ___ ___IN=___ M MN = ______ M	___ ___ ___ ___IN=___ M MN = ______ M	___ ___ ___ ___IN=___ M MN = ______ M
MN ADJ TO VERT:	______ M	______ M	______ M

****

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	______	______	______	______	______	______
LONG	______	______	______	______	______	______
HT	______	______	______	______	______	______
PDOP	______	______	______	______	______	______
SVS TO TRACK	____________		____________		____________	
	____________		____________		____________	
LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	______	______	______	______	______	______
STOP	______	______	______	______	______	______

****

PAGE 1

a. Front

Figure 9-4. Worksheet 9-1, USACE GPS Data Logging Sheet

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

****

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	________	________	________
POWER SUPPLY	________	________	________
WEATHER CONDITIONS	________	________	________
MONUMENT TYPE	________	________	________
EXACT STAMPING	________	________	________
AGENCY CAST IN DISK	________	________	________

****

SKETCH OF SITE

SESSION 1	SESSSION 2	SESSION 3

****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurence and duration.

****

PAGE 2

b. Back

Figure 9-4. (Concluded)

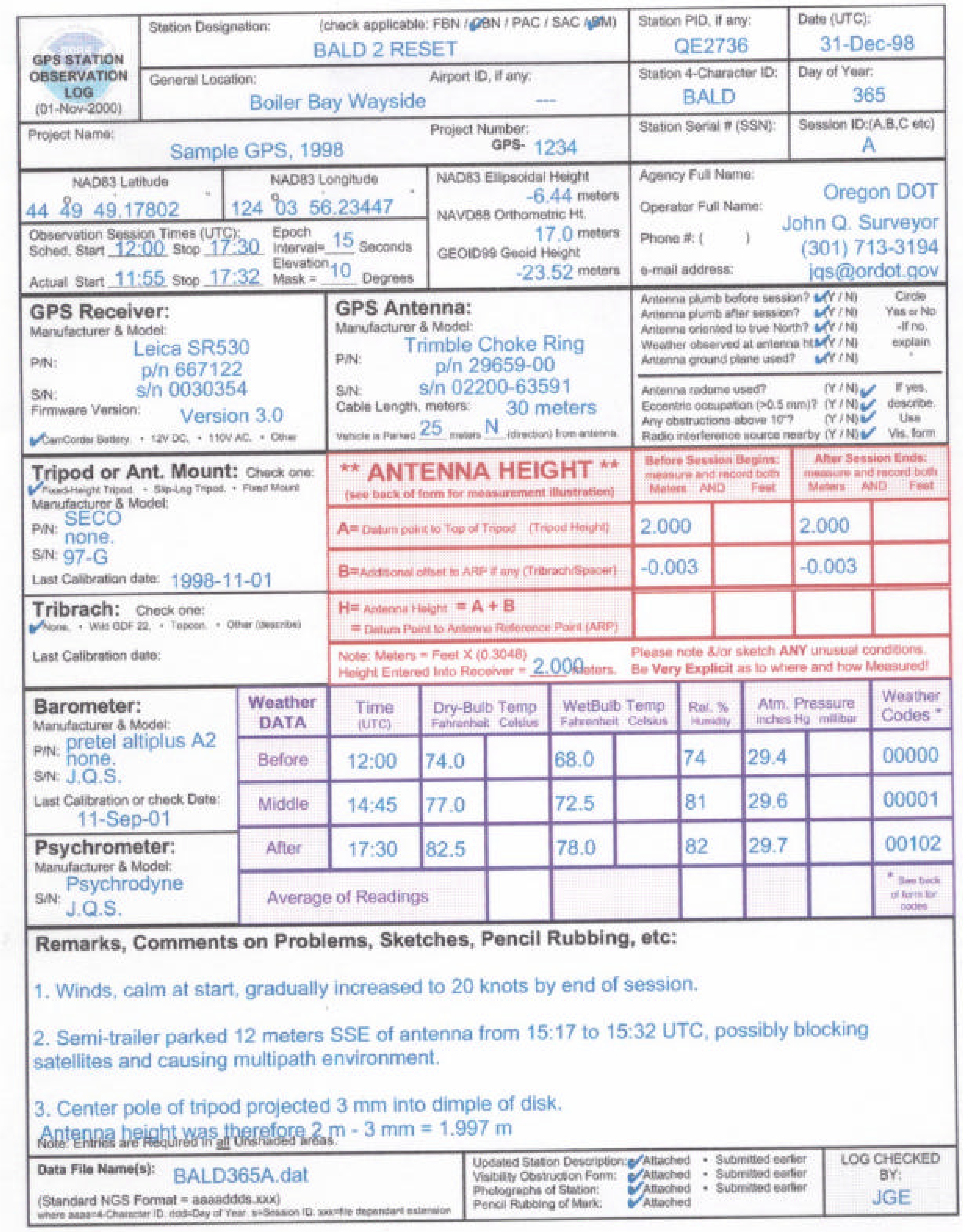
GPS SESSION FORM **CORPS OF ENGINEERS, JACKSONVILLE DISTRICT**

<table>
<tr><td>Jax Survey No.</td><td colspan="3">Project Name</td><td>Date</td></tr>
<tr><td>Agency/AE Project No.</td><td colspan="2">Agency/AE Firm</td><td colspan="2">Operator Name</td></tr>
<tr><td colspan="2">Monument Name/Designation</td><td colspan="3">Exact Stamping (include photo in survey report)</td></tr>
<tr><td>Monument No./PID</td><td>Agency Cast in Disk</td><td colspan="3">File Name (receiver generated)</td></tr>
<tr><td colspan="2">Receiver Manufacturer</td><td>Receiver Model</td><td colspan="2">Receiver Serial No.</td></tr>
<tr><td colspan="2">Data Collector Manufacturer</td><td>Data Collector Model</td><td colspan="2">Data Collector Serial No.</td></tr>
<tr><td colspan="2">Antenna Part No.</td><td>Antenna Model</td><td colspan="2">Antenna Serial No.</td></tr>
<tr><td colspan="2">Starting Antenna Height in Feet
1 2 3 AVG</td><td>Starting Antenna Height Meters
1 2 3 AVG</td><td colspan="2">Type of Measurement (circle one)
TRUE VERTICAL SLANT</td></tr>
<tr><td colspan="2">Ending Antenna Height in Feet
1 2 3 AVG</td><td>Ending Antenna Height in Meters
1 2 3 AVG</td><td colspan="2">Type of Measurement (circle one)
TRUE VERTICAL SLANT</td></tr>
<tr><td colspan="5">Antenna Reference Point (include and reference a dimensioned diagram in Survey Report)
e.g., bottom edge of notch in ground plane, Page 5, Figure 2</td></tr>
<tr><td colspan="2">Start Date (UTC)</td><td>Start Time (UTC)</td><td colspan="2">Approx. Lat. (if available)</td></tr>
<tr><td colspan="2">End Date (UTC)</td><td>End Time (UTC)</td><td colspan="2">Approx. Lon. (if available)</td></tr>
<tr><td colspan="2">Describe any abnormalities and/or problems encountered during the session, include time of occurrence and duration.</td><td colspan="3">Site Diagram</td></tr>
</table>

version 20020912

ALL FIELDS REQUIRED UNLESS OTHERWISE NOTED
SUBMIT DIGITAL COPY OF ORIGINAL AND TYPED VERSIONS

Figure 9-5. Jacksonville District GPS Session Recording Form



GPS STATION OBSERVATION LOG (01-Nov-2000)

Station Designation: (check applicable: FBN / CBN / PAC / SAC / PM) BALD 2 RESET

Station PID, if any: QE2736

Date (UTC): 31-Dec-98

General Location: Boiler Bay Wayside

Airport ID, if any: ---

Station 4-Character ID: BALD

Day of Year: 365

Project Name: Sample GPS, 1998

Project Number: GPS- 1234

Station Serial # (SSN):

Session ID:(A,B,C etc) A

NAD83 Latitude: 44 49 49.17802

NAD83 Longitude: 124 03 56.23447

NAD83 Ellipsoidal Height: -6.44 meters

NAVD88 Orthometric Ht. 17.0 meters

GEOID99 Geoid Height -23.52 meters

Observation Session Times (UTC): Sched. Start 12:00 Stop 17:30; Actual Start 11:55 Stop 17:32

Epoch Interval= 15 Seconds

Elevation Mask = 10 Degrees

Agency Full Name: Oregon DOT

Operator Full Name: John Q. Surveyor

Phone #: ( ) (301) 713-3194

e-mail address: jqs@ordot.gov

GPS Receiver:
Manufacturer & Model: Leica SR530
P/N: p/n 667122
S/N: s/n 0030354
Firmware Version: Version 3.0
CamCorder Battery. • 12V DC. • 110V AC. • Other

GPS Antenna:
Manufacturer & Model: Trimble Choke Ring
P/N: p/n 29659-00
S/N: s/n 02200-63591
Cable Length, meters: 30 meters
Vehicle is Parked 25 meters N (direction) from antenna.

Antenna plumb before session? (Y / N)
Antenna plumb after session? (Y / N)
Antenna oriented to true North? (Y / N)
Weather observed at antenna ht? (Y / N)
Antenna ground plane used? (Y / N)
Circle Yes or No -If no, explain

Antenna radome used? (Y / N)
Eccentric occupation (>0.5 mm)? (Y / N)
Any obstructions above 10°? (Y / N)
Radio interference source nearby (Y / N)
If yes, describe. Use Vis. form

Tripod or Ant. Mount: Check one:
Fixed-Height Tripod. • Slip-Leg Tripod. • Fixed Mount
Manufacturer & Model: SECO
P/N: none.
S/N: 97-G
Last Calibration date: 1998-11-01

Tribrach: Check one:
None. • Wild GDF 22. • Topcon. • Other (describe)
Last Calibration date:

** ANTENNA HEIGHT **
(see back of form for measurement illustration)

	Before Session Begins: measure and record both Meters	Feet	After Session Ends: measure and record both Meters	Feet
A= Datum point to Top of Tripod (Tripod Height)	2.000		2.000	
B=Additional offset to ARP if any (Tribrach/Spacer)	-0.003		-0.003	
H= Antenna Height = A + B = Datum Point to Antenna Reference Point (ARP)				

Note: Meters = Feet X (0.3048)
Height Entered Into Receiver = 2.000 Meters.

Please note &/or sketch ANY unusual conditions. Be Very Explicit as to where and how Measured!

Barometer:
Manufacturer & Model:
P/N: pretel altiplus A2
none.
S/N: J.Q.S.
Last Calibration or check Date: 11-Sep-01

Psychrometer:
Manufacturer & Model: Psychrodyne
S/N: J.Q.S.

Weather DATA	Time (UTC)	Dry-Bulb Temp Fahrenheit	Dry-Bulb Temp Celsius	WetBulb Temp Fahrenheit	WetBulb Temp Celsius	Rel. % Humidity	Atm. Pressure inches Hg	Atm. Pressure millibar	Weather Codes *
Before	12:00	74.0		68.0		74	29.4		00000
Middle	14:45	77.0		72.5		81	29.6		00001
After	17:30	82.5		78.0		82	29.7		00102
Average of Readings									* See back of form for codes

Remarks, Comments on Problems, Sketches, Pencil Rubbing, etc:

1. Winds, calm at start, gradually increased to 20 knots by end of session.

2. Semi-trailer parked 12 meters SSE of antenna from 15:17 to 15:32 UTC, possibly blocking satellites and causing multipath environment.

3. Center pole of tripod projected 3 mm into dimple of disk.
Antenna height was therefore 2 m - 3 mm = 1.997 m

Note: Entries are Required in all Unshaded areas.

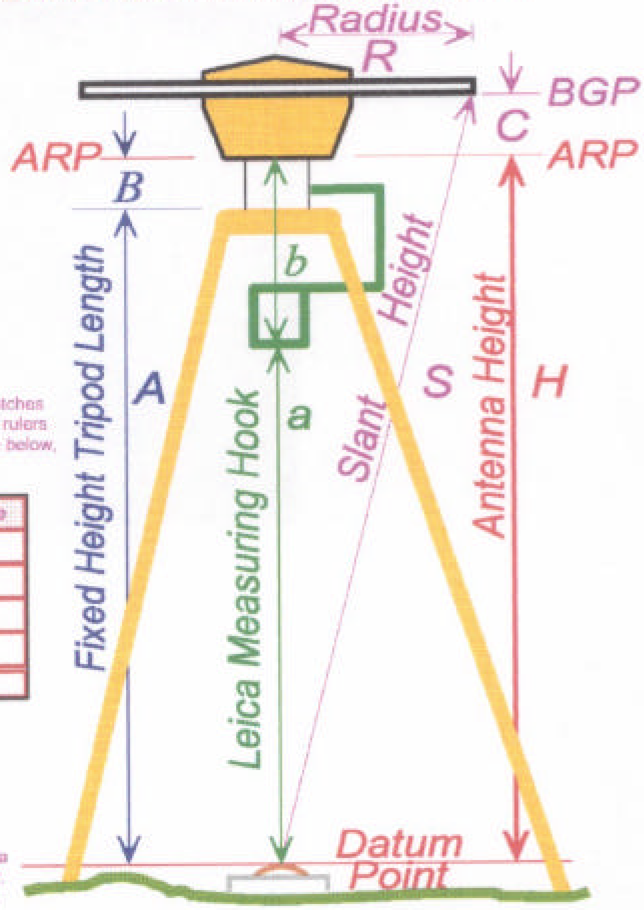
Data File Name(s): BALD365A.dat
(Standard NGS Format = aaaaddds.xxx)
where aaaa=4-Character ID. ddd=Day of Year. s=Session ID. xxx=file dependant extension

Updated Station Description: Attached • Submitted earlier
Visibility Obstruction Form: Attached • Submitted earlier
Photographs of Station: Attached • Submitted earlier
Pencil Rubbing of Mark: Attached

LOG CHECKED BY: JGE

Figure 9-6. NGS Station Observation Log (Page 1)

ILLUSTRATION FOR ANTENNA HEIGHT MEASUREMENTS:



I. Instructions for Fixed-Height Tripods:

Measure & record the fixed-height tripod length **(A)** and other offsets, if any, between the tripod and the Antenna Reference Point (ARP) **(B)**

$$Antenna.Height = H = A + B$$

II. Instructions for Slip-Leg Tripods:

1. Measure the Slant Height (S)

Measure the slope distance from the mark to at least three notches on the Bottom of Ground Plane (BGP) using two independent rulers (e.g., metric and Imperial). Record measurements in the table below, and compute the average.

Measure S	Notch #_	Notch #_	Notch #_	Average
Before, cm	223.40	223.30	223.30	
Before, inch	87.95	87.94	87.93	
After, cm	223.40	223.40	223.30	
After, inch	87.97	87.96	87.95	
Note: cm= inch x (2.54)	Overall average, cm			

S = ______________ cm

2. Record the Antenna Radius (R) and the Antenna Constant (C)

The antenna radius (R) is the horizontal distance from the center of the antenna to the measurement notch. The antenna constant (C) is the vertical distance from the ARP to the BGP. Consult your antenna users manual for exact measurements.

R = 19.05 cm

C = 3.50 cm

3. Compute Antenna Height (H)

Use the following Pythagorean equation:

$$Antenna.Height = H = ((\sqrt{S^2 - R^2}) - C)$$

III. Instructions for using the Leica Brand Measuring Hook:

Follow the Leica operating instructions, being sure to reduce the height to the Antenna Reference Point (ARP), NOT the L1 Phase Center.

$$Antenna.Height = H = a + b$$

Table of Weather Codes -- for entry into Weather Data Table on front of form:					
CODE	PROBLEM	VISIBILITY	TEMPERATURE	CLOUD COVER	WIND
0	NO PROBLEMS encountered	GOOD More than 15 miles	NORMAL 32° F to 80°F	CLEAR Below 20%	CALM Under 5mph (8km/h)
1	PROBLEMS encountered	FAIR 7 to 15 miles	HOT Over 80°F (27 C)	CLOUDY 20% to 70%	MODERATE 5 to 15 mph
2	– NOT USED –	POOR Less than 7 miles	COLD Below 32° F (0 C)	OVERCAST Over 70%	STRONG over15mph (24km/h)
Examples: Code 00000 = Code 12121 =	0 - No problems, 1 - Problems,	0 - good visibility, 2 - poor visibility,	0 - normal temperature, 1 - hot temperature,	0 - clear sky, 2 - overcast,	0 - calm wind 1 - moderate wind

Figure 9-6. (Concluded) NGS Station Observation Log (Page 2)

Section I: Conducting Absolute GPS Positioning and Navigation Surveys

9-3. General

Absolute point positioning GPS receivers acquire and process satellite range data to provide 10-30 meter horizontal accuracy positions. This real-time positional data is typically displayed on a hand-held receiver screen, either in numeric or graphic (navigation) format, depending on the application. Numerous hand-held receivers are available for real-time dynamic navigation uses. Although absolute positional data are most often expressed in real time, some mapping-grade receivers can post-process data if station occupation was static over a period of time--e.g., 6 to 24 hours. The post-processing produces a best-fit point position and meter-level accuracy can be achieved--dual-frequency receivers using the precise ephemeris can produce even better (sub-meter) absolute positional accuracies. Absolute positions are based on the WGS 84 ellipsoid. Therefore, observed horizontal positions need to be transformed to a local reference datum (e.g., NAD 83) and ellipsoid elevations need to be corrected for geoid undulation in order to obtain approximate orthometric elevations on either NAVD 88 or NGVD 29.

9-4. Absolute Point Positioning Techniques

Absolute point positioning techniques are employed where differential techniques are impractical and a new reference point is needed. This might occur in some OCONUS locations. Given the ready availability of automated differential techniques in CONUS (e.g., FAA WAAS, USCG radiobeacon) there is no longer any need to perform absolute point positioning. There are two techniques used for point positioning in the absolute mode. They are long term averaging of positions and differencing between signals.

a. In long-term averaging, a receiver is set up to store positions over a fixed period of time. The length of observation time varies based upon the accuracy required. The longer the period of data collection, the better the average position will be. This observation time can range between 1 and 24 hours. This technique can also be done in real-time (i.e. the receiver averages the positions as they are calculated). For example, the military PLGR GPS receiver uses this technique in calculating a position at a point. Positions can be stored at either 15, 30, or 60 second intervals, depending on storage capacity and length of observation. Typically, a 24-hour observation period is used to obtain an absolute point position accurate to the meter-level.

b. The process of differencing between signals can only be performed in a post-processed mode. NIMA (formerly Defense Mapping Agency) has produced software that can perform this operation. There are few USACE requirements for this technique.

9-5. Absolute GPS Navigation Systems

General vehicle and vessel navigation systems typically use inexpensive single-frequency GPS receivers. Various types of these receivers are sold at prices ranging from $100 to $1,000, depending largely on the display and software options. Operation of these receivers is simple and briefly explained in operating manuals provided with the device. Some receivers can log feature data for subsequent download to a GIS. Other receivers can log code and carrier phase data for post-processing adjustment to a reference station such as CORS. A typical receiver is shown in Figure 9-7. This receiver weighs only 5.3 ounces and has a high-contrast LCD display. It can save up to 500 waypoints and contains more than 100 map datums.

Figure 9-7. Garmin eTrex handheld differential-ready 12 parallel channel GPS receiver

9-6. Mapping Grade GPS Receivers

Figure 9-8. Real-time, meter-level accuracy, feature mapping-grade GPS backpack systems

A variety of mapping grade GPS receivers are available to collect and process real-time absolute and code differential positional data, post-processed carrier differential positional data, and correlate these positions with CADD/GIS map features. These georeferenced features can then be exported into a specific GIS platform. These mapping grade receiver systems, including software, range in cost between $3,000 and $10,000. Field operation of these receivers is fairly straightforward and is described in operating manuals referenced in the following sections. The following paragraphs briefly describe some of the operational capabilities of two Trimble mapping grade receivers: the GeoExplorer 3 and the GPS Pathfinder.

a. Trimble GeoExplorer 3. The GeoExplorer 3 data collection system is an integrated GPS receiver and data collector for mapping, relocating, and updating GIS and spatial data. The system is used with the GPS Pathfinder Office software for mission planning, data transfer, data dictionary creation, data import/ export, and post-processing. The GeoExplorer 3 data collection system can operate as a rover receiver or as a base station--typically using meter-level accuracy code data acquired from USCG radiobeacon stations or from commercial wide area providers. It can also collect high-precision data using differential GPS carrier phase measurements. The data collector can navigate, collect data, view system status and satellite availability, and control the GPS receiver. The GeoExplorer 3 data logger is designed for handheld use in the field. It has an internal antenna and power source, and a high-performance 12-channel GPS receiver. Accessories, such as external antennas or power kits, are available. The primary functions of the GeoExplorer 3 data collection system are collecting geographic data, using and updating existing GIS data, and navigating in the field. It can collect the feature attributes and GPS position of geographic points, lines, and areas. This information is stored in one or more data files that can later be transferred to Trimble's GPS Pathfinder Office software for postprocessing and editing. Data can then be exported into a variety of CADD/GIS compatible formats. The GeoExplorer 3 can be configured to update data from an existing GIS or CADD database. It can also be used to navigate to specific locations, using either absolute point positioning or real-time differential GPS, using the optional Beacon-on-a-Belt (BoB) beacon receiver. Feature data dictionaries can be created or edited in the office with the GPS Pathfinder Office software or in the GeoExplorer 3 data collection system. Applications for the GeoExplorer 3 include utility mapping and locating, forestry mapping, environmental and resource management, disaster assessment, and urban asset management. For further details on the GeoExplorer 3 system refer to *GeoExplorer 3 Operation Guide* (Trimble 2001f).

b. Trimble Pathfinder Pro XR/XRS. The Pathfinder Pro XR/XRS 12-channel, dual-frequency receivers are capable of processing absolute GPS positioning data, MSK radiobeacon DGPS code corrections, and satellite differential corrections from commercial providers, such as Fugro OmniSTAR and Thales LandSTAR. These systems can also process code differential corrections from an external fixed reference receiver--such that decimeter-level and centimeter-levels can be obtained. The GPS and radiobeacon antennas are combined into a single unit. Sub-meter positional accuracy is achieved if a compatible Trimble reference station is used. More accurate differential carrier phase data can also be collected for post-processing. Carrier phase data and mapped feature data can be exported to a post-processing program such as Pathfinder Office. The Pathfinder system is typically configured in a backpack assembly that contains the receiver, battery pack, antenna pole, and GPS/MSK beacon antenna. For further details on this system, see *GPS Pathfinder Systems Receiver Manual* (Trimble 2001e).

c. GPS Pathfinder Office. GPS Pathfinder Office is typical of software designed to manage and process data collected by mapping grade GPS receivers. It is especially designed to configure and export feature data into GIS or CADD databases. Other features include: design or construction of feature data dictionaries, CADD/GIS database format conversions, file transferring from handheld data collectors, and differentially processing GPS data between a reference base station and a rover unit. This processing software is described in *GPS Pathfinder Office* (Trimble 2002a).

Section II: Conducting Differential GPS Code Phase Positioning and Mapping Surveys

9-7. General

Differential (or relative) GPS surveying is the determination of one location with respect to another location. When using this technique with the C/A or P-code it is called differential code phase positioning, as distinct from carrier phase positioning techniques covered in the next section. Differential code phase positioning has limited application to detailed engineering control surveying and topographic site plan mapping applications. However, it is widely used for general reconnaissance surveys, hydrographic survey positioning, offshore core drilling rig positioning, dredge positioning, and some operational military survey support functions. Additional applications for relative code phase positioning have been on the increase as positional accuracies have improved. Real-time, meter-level DGPS correctors can be obtained from the USCG radiobeacon navigation service or from a variety of commercial wide-area augmentation systems. This section primarily focuses on the USCG radiobeacon system; however, a number of commercial augmentation systems are also capable of providing comparable (or better) survey positioning capability. Some of those commercial systems having USACE application are described. Calibration guidance in this section is applicable to all these augmentation systems.

9-8. USCG DGPS Radiobeacon Navigation Service

a. *General.* The USCG radiobeacon system is by far the most widely applied use of code phase GPS in USACE--in fact, the Corps funds and operates some USCG radiobeacon stations at various points along the Mississippi River and tributaries. This real-time positioning system is used for nearly all dredge positioning and hydrographic survey operations in USACE. In the past, Loran-C and Omega systems were used as the primary positioning tools for marine navigation. Today, the USCG is making use of the full coverage from GPS for a more accurate positioning tool for marine navigation. Utilizing DGPS and marine radiobeacon technology, the USCG has designed a real-time positioning system for the coastal areas and Great Lakes regions of the US. The USCG has also partnered with USACE and other government agencies to expand this coverage to inland waterways and eventually over the entire nation. The system consists of a series of GPS reference stations with known coordinate values based on the North American Datum of 1983 (NAD 83) datum. GPS C/A-code pseudorange corrections are computed based on these known coordinate values and transmitted via a marine radiobeacon. A user with a marine radiobeacon receiver and a GPS receiver with the ability to accept and apply pseudorange corrections can obtain a relative accuracy of 0.5-3 meters. This accuracy is dependent on many factors including the design and quality of the user's GPS receiver, distance from the reference station, and the satellite geometry. This service can be used for all USACE hydrographic surveys and dredge positioning requiring an accuracy of 0.5 to 3 meters.

b. Site set-up and configuration. Each USCG radiobeacon site consists of two GPS L1/L2 geodetic receivers (as reference station receivers) with independent geodetic antennas to provide redundancy, and a marine radiobeacon transmitter with transmitting antenna. The site is also equipped with two combined L1 GPS / Modulation Shift Key (MSK) receivers which are used as integrity monitors. Each combined receiver utilizes an independent GPS antenna and a MSK near-field passive loop antenna.

(1) Site Location. The location of the reference station GPS antennas are tied into the North American Datum of 1983 (NAD 83) and the International Terrestrial Reference Frame (ITRF). The geodetic coordinates for these positions were determined by NGS. DGPS pseudorange corrections are based on measurements made by the reference receiver relative to the NAD 83 antenna coordinates.

These pseudorange corrections are then transmitted via the marine radiobeacon to all users having the necessary equipment.

(2) Data Transmission (data types). The corrections are transmitted using the Type 9-3 message format designated by the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104). Other RTCM SC-104 message types transmitted to the user include Type 3 (contains the NAD 83 coordinates for the broadcast site), Type 5 (provides information if a GPS satellite is deemed unhealthy), Type 7 (information on adjacent radiobeacons), and Type 16 (alerts the user of any outages). More detailed descriptions of these message types can be downloaded from the USCG Navigation Center (NAVCEN) web site.

(a) Pseudorange corrections are generated for a maximum of nine satellites tracked by the reference station GPS receiver at an elevation angle of 5 degrees or higher above the horizon. Satellites below a 5-degree elevation mask are highly susceptible to multipath and spatial decorrelation. If there are more than nine satellites observed at the reference station above 5 degrees, then the corrections broadcast are based on the nine satellites with the highest elevation angle.

(b) The sites transmit these corrections at a 100 or 200 baud rate. Since a Type 9-3 message is 210 bits (includes header information and corrections for three satellites), the latency of the data is 2.1 seconds for a site transmitting at 100 baud. For stations transmitting at 200 baud, the latency would be half, or 1.05 seconds. The user can expect a latency of 2 to 5 seconds for all of the corrections for a group of satellites observed at the reference station to reach them. A correction can be considered valid for a period of 10 to 15 seconds from generation (the USCG limit is 30 seconds). Using corrections beyond this period of time, especially for positioning of a moving platform, may cause spikes in the positional results.

c. Availability and reliability of the system. The system was designed for and operated to maintain a broadcast availability (i.e. transmitting healthy pseudorange corrections) that exceeds 99.7% (in designed coverage areas) assuming a healthy and complete GPS constellation. The signal availability, in most areas, will be higher due to the overlap of broadcast stations. The USCG monitors each site within the entire system for problems or errors, and immediately alerts users of any problems. Each site is equipped with two integrity monitors (i.e. a GPS receiver with a MSK radiobeacon) whose antennas are mounted over known positions. The integrity monitors receive the pseudorange corrections from that site and compute a check position. The computed or corrected position is compared to the known location to determine if the corrections are within the expected tolerance. The corrected positions calculated by the integrity monitors are sent via phone lines to the control monitoring stations. For the stations east of the Mississippi River, this information is sent to USCG's NAVCEN in Alexandria, Virginia. Sites west of the Mississippi River send their corrected positions to the NAVCEN Detachment in Petaluma, California. Users are notified via the type 16 message of any problems with a radiobeacon site within 10 seconds of an out-of-tolerance condition.

d. Coverage. The system was designed to cover all harbors and harbor approach areas and other critical waterways for which USCG provides aids to navigation. Each site has a coverage area between 150 to 300 miles, depending on the transmitter power, terrain, and signal interference. Since the sites utilize an omnidirectional transmitting antenna, some areas have overlapping coverage. Currently the system covers all US coastal harbor areas, the Mississippi and part of the Missouri and Ohio Rivers, and the Great Lakes Region. Additional areas within the Midwest and other non-coastal areas are being added to provide nationwide coverage, under the Nationwide DGPS program (NDGPS). Figure 9-9 depicts existing and planned radiobeacon coverage as of 2002. An updated map of the coverage area can be found at the NAVCEN web site under the DGPS section.

e. User requirements and equipment. To receive and apply the pseudorange corrections generated by the reference station, the user needs to have a MSK radiobeacon receiver with antenna and, at a minimum, a L1 C/A-code GPS receiver with antenna. The MSK receiver demodulates the signal from the reference station. Most MSK receivers will automatically select the reference station with the strongest signal strength to observe from or allow the user to select a specific reference station. A MSK receiver can be connected to most GPS receivers. The costs of radiobeacon receivers range from $500 to $2000. The GPS receiver must be capable of accepting RTCM Type 9 messages and applying these corrections to compute a "meter-level" position. Since the reference station generates corrections only for satellites above a 7.5-degree elevation, satellites observed by the user's GPS receiver below a 7.5-degree elevation will not be corrected. Some receiver manufacturers have developed a combined MSK radiobeacon and GPS receiver with a combined MSK and GPS antenna. For a combined radiobeacon/GPS receiver, prices range from $2,000 to $5,000.

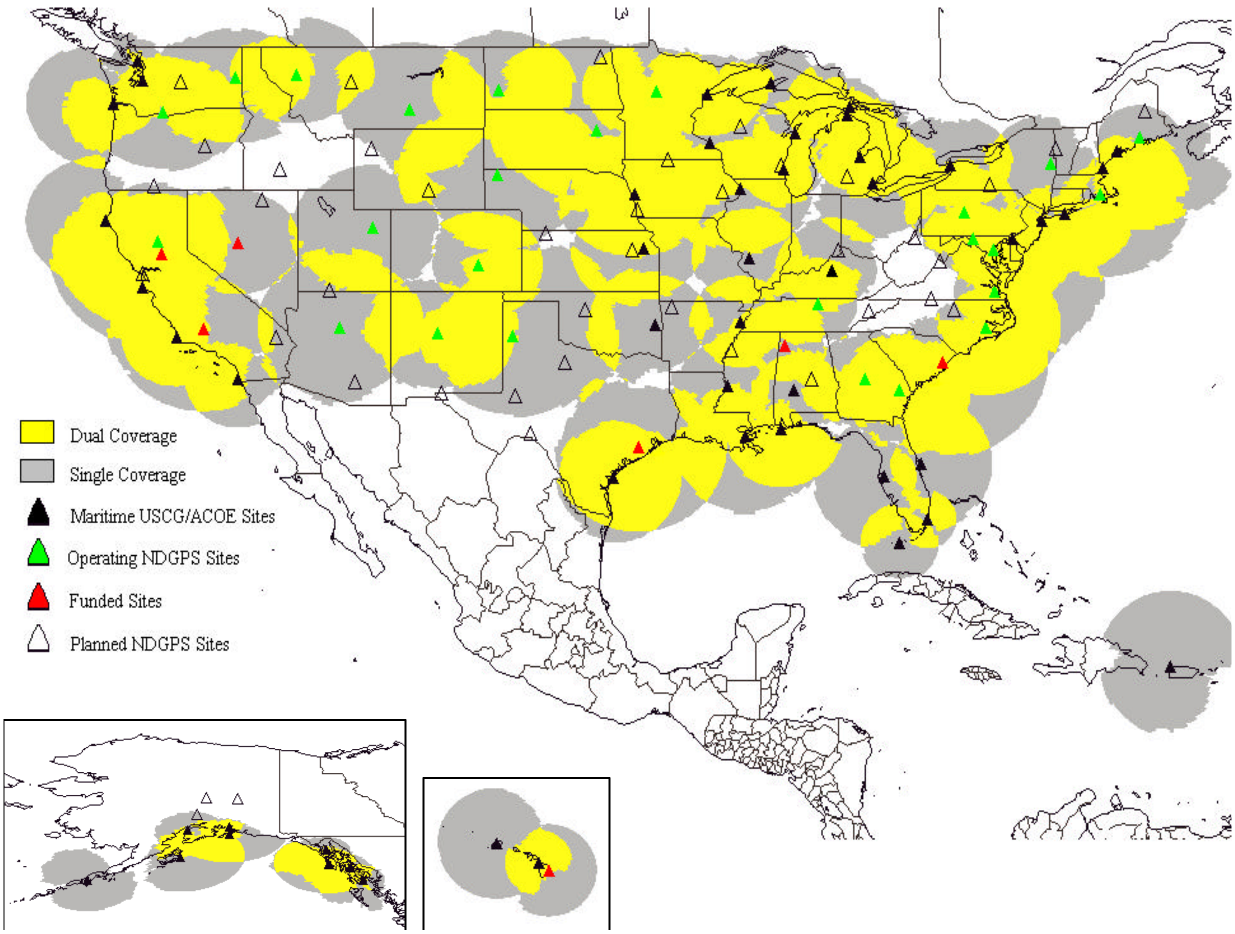


Figure 9-9. USCG Radiobeacon MDGPS and NDGPS coverage--current (2002) and planned stations

f. Position QC tolerance checks. Most precise DGPS augmentation systems are capable of providing sub-meter accuracies at reasonable distances from the nearest reference station. However, at increasing distances, spatial decorrelation errors (due to differing ionospheric/tropospheric conditions) can induce systematic positional biases. In general, under nominal atmospheric conditions, a 2-meter RMS (95%) positional accuracy may be achieved at distances upwards of 150 miles. To confirm a positional accuracy is within this 2-meter tolerance, it is strongly recommended that a static check position be obtained at some known survey point near the project. When operating with the USCG radiobeacon system, static positions should be observed from different radiobeacon reference stations to ascertain if positional systematic biases are present--and select the beacon with minimal biases. In practice, this would normally be the closest beacon. If no fixed survey point is available, then a static comparison of different beacon positions should be observed; however, any large biases between beacon positions may be ambiguous. When large or ambiguous positional biases occur in a project area, it may be necessary to establish a local DGPS network (code or RTK carrier) if high positional accuracy is critical to the project. Commercial wide area DGPS systems should be checked in a similar manner.

9-9. FAA Wide Area Augmentation System (WAAS)

The FAA's WAAS is a GPS-based navigation and landing system that will provide precision guidance to aircraft at thousands of airports and airstrips where there is currently no precision landing capability. Although still under development, this system will have potential USACE positioning, mapping, and navigation applications; either as a primary or supplemental positioning system. Many GPS receivers have been developed to acquire and process FAA WAAS signals--e.g., Garmin, Magellan, Trimble ProXR/XRS. As with most augmentation systems, WAAS is designed to improve the accuracy and ensure the integrity of information coming from GPS satellites.

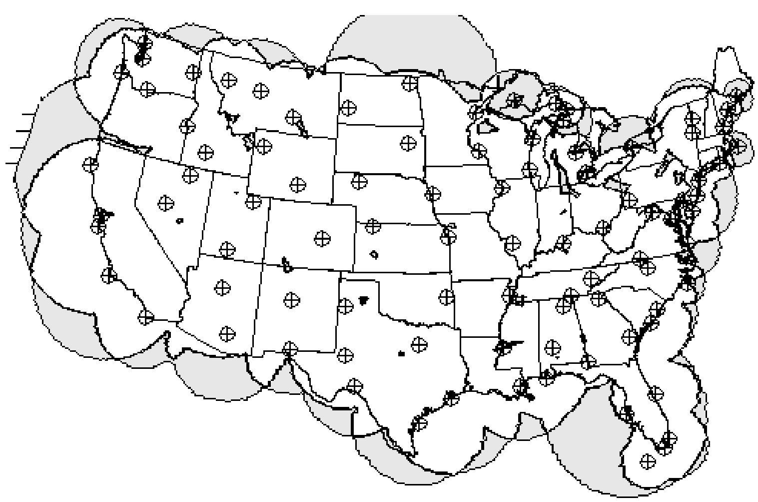


Figure 9-10. Proposed FAA WAAS coverage in CONUS

a. FAA WAAS is based on a network of ground reference stations that cover a very large service area--see Figure 9-10. Signals from GPS satellites are received by wide area ground reference stations (WRSs). Each of these precisely surveyed reference stations receives GPS signals and determines if any errors exist. These WRSs are linked to form the US WAAS network. Each WRS in the network relays the data to the wide area master station (WMS) where correction information is computed. The WMS calculates correction algorithms and assesses the integrity of the system. A correction message is prepared and uplinked to a geosynchronous satellite via a ground uplink system. The message is then broadcast from the satellite on the same frequency as GPS (L1--1575.42 MHz) to receivers on board aircraft (or ground-based hand-held receivers) that are within the broadcast coverage area and are capable of receiving FAA WAAS corrections. These communications satellites also act as additional navigation satellites for the aircraft, thus providing additional navigation signals for position determination. The FAA WAAS will improve basic GPS accuracy to approximately 7 meters vertically and horizontally, improve system availability through the use of geostationary communication satellites (GEOs) carrying navigation payloads, and provide important integrity information about the entire GPS constellation.

b. At present there are two geostationary satellites serving the WAAS area (Inmarsat IIIs: POR (Pacific Ocean Region) and AOR-W (Atlantic Ocean Region-West)--see Figure 9-11. The European area will eventually be served by two Inmarsats, AOR-E (Atlantic Ocean Region-East) and IOR (Indian Ocean Region) and the European Space Agency satellite, ARTEMIS. Europe's Geostationary Navigation Overlay Service (EGNOS) is Europe's first venture into satellite navigation and is Europe's first stage of the Global Navigation Satellite System (GNSS). EGNOS is a precursor to GALILEO, the full global satellite navigation system under development in Europe. On the future ARTEMIS satellite, the GPS/GLONASS augmentation is made directly from aircraft based equipment. In Asia, Japan is developing the Multi-functional Satellite Augmentation System (MSAS).

c. EGNOS & WAAS do not currently share almanac information, and EGNOS is broadcasting a "do not use" indication. So it is unlikely that users in Europe will see any response from EGNOS until their systems share more information and allow use of the corrections.

d. Garmin WAAS receiver operation. Garmin is typical of receivers that have been configured to receive FAA WAAS corrections. Garmin units can access 19 WAAS/EGNOS/MSAS unique GEO satellites. They are depicted on the GPS as Satellite IDs 33-51, which is actually a NMEA convention. Each WAAS/EGNOS/MSAS satellite will have its own unique PRN code assigned from the list of 19. These satellites do not move on the screen as do the other GPS low-earth-orbit satellites. Garmin receivers use one or two channels to track WAAS satellites and they will use the WAAS satellite in the position solution, if the WAAS system indicates it is OK to use for navigation. Sometimes the WAAS satellite is flagged as "do not use for navigation" but the corrections are still useful.

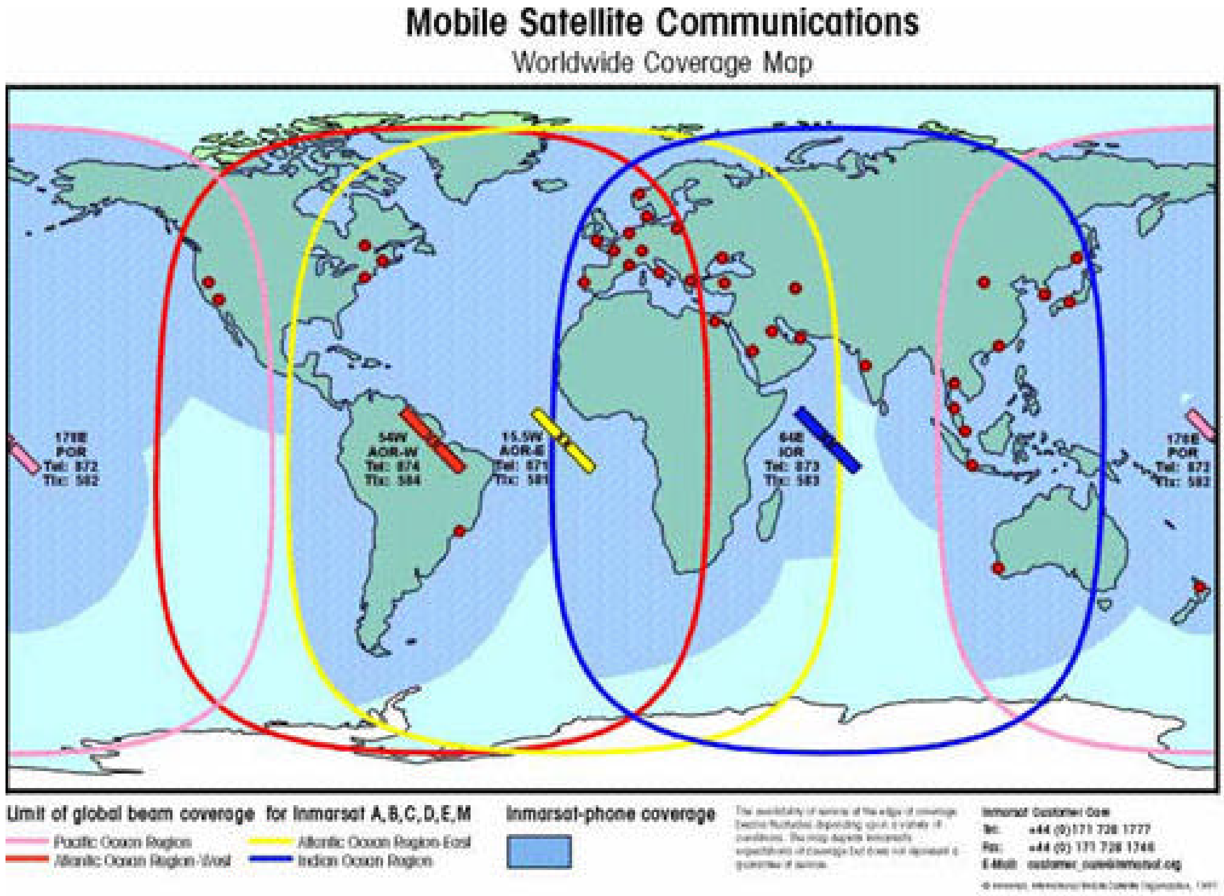


Figure 9-11. Inmarsat global coverage

9-10. FAA Local Area Augmentation System (LAAS)

The FAA is also developing a Local Area Augmentation System (LAAS) for high accuracy aircraft landing. This LAAS will include a ground facility that has four Reference Receivers (RR), RR antenna pairs, redundant Very High Frequency Data Broadcast (VDB) equipment feeding a single VDB antenna, and equipment racks. These sets of equipment are installed on the airport property where LAAS is intended to provide service. The ground facility receives, decodes, and monitors GPS satellite information and produces correction messages. To compute corrections, the ground facility calculates position based on GPS, and then compares this position to their known location. Once the corrections are computed, a check is performed on the generated correction messages to help ensure that the messages will not produce misleading information for the users. This correction message, along with suitable integrity parameters and approach path information, is then sent to the airborne LAAS user(s) using the VDB from the ground-based transmitter. Airborne LAAS users receive this data broadcast from the ground facility and use the information to assess the accuracy and integrity of the messages, and then compute accurate Position, Velocity, and Time (PVT) information using the same data. This PVT is utilized for the area navigation guidance and for generating Instrument Landing System (ILS)-look-alike guidance to aid the aircraft on an approach. Although these FAA LAAS systems will not have any direct USACE application, the technology developed by the FAA may have use on unique Corps projects where high-accuracy real-time positioning is required, such as in obstructed areas.

9-11. OmniSTAR Wide-Area Differential Positioning Service

OmniSTAR is typical of a commercial "fee-for-service" wide-area differential GPS system, using satellite broadcast techniques to deliver accurate GPS correctors. Data from many widely spaced reference stations is used in a proprietary multi-site solution to achieve sub-meter positioning over most land areas worldwide. OmniSTAR is proprietary system operated by the Fugro group. Corps applications include all mapping and navigation solutions where the USCG or FAA WAAS systems are not available or are blocked.

a. OmniSTAR provides worldwide DGPS coverage with 70 reference stations around the globe and 3 network control centers. The OmniSTAR service was developed to satisfy the need for an accurate positioning system for new applications on land. The OmniSTAR service offers real-time, DGPS positioning. The system is characterized by portable receiving equipment, suitable for vehicle mounting or "back-pack" use. OmniSTAR supports applications across a wide range of industries including agriculture (precision farming), mining, and land survey. Aerial applications include crop dusting and geophysical surveys.

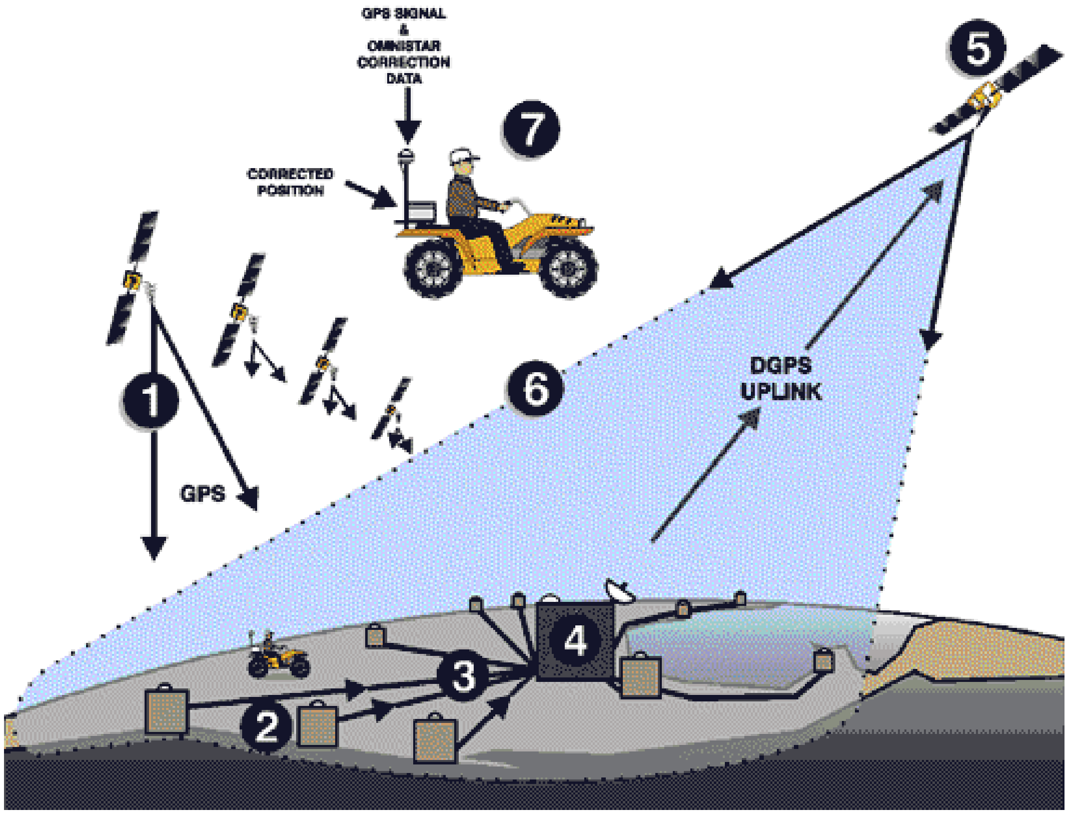


Figure 9-12. OmniSTAR concept. 1. GPS satellites. 2. Multiple OmniSTAR GPS monitor sites. 3. Send GPS corrections via lease line to 4. Houston Network Control Center where data corrections are checked and repackaged for uplink to 5. L-Band Geostationary Satellite. 6. GE Spacenet 3 broadcast footprint OmniSTAR user area. 7. Correction data are received and applied real-time.

OmniSTAR's "Virtual Base Station" technology generates corrections optimized for the user's location. OmniSTAR receivers output both high quality RTCM SC-104 Version 2 corrections and differentially corrected Lat/Long in NMEA format.

b. Technical description. The OmniSTAR system generates pseudorange corrections for differential users. This is accomplished by the use of one or more "Base Stations" that measure the errors in the GPS pseudoranges and generates corrections. The method of generating corrections is similar to other DGPS service systems. The OmniSTAR DGPS System was designed with the following objectives: (1) continental coverage; (2) sub-meter accuracy over the entire coverage area; and (3) a portable system. The first objective dictated that transmission of the corrections had to be from a geostationary satellite. The AMSC Satellite, located at 101 degrees West Longitude, has three individual beams that together cover all of North America from 60 degrees North Latitude to the Southern border of Mexico. It has sufficient power within that footprint that a small omnidirectional antenna may be used for receiving. The frequency of the OmniSTAR Geostationary Satellite is sufficiently close to that of GPS that in most instances, a common, single antenna, may be used. The methodology developed by OmniSTAR consists of using multiple GPS base stations in a user's solution and reducing errors due to the GPS signal traveling through the atmosphere. OmniSTAR was the first widespread use of a "Wide Area DGPS Solution." The OmniSTAR solution uses data from a relatively small number of base stations to provide consistent accuracy over large areas. A method of solving for atmospheric delays and weighting of distant base stations achieves sub-meter capability over the entire coverage area--regardless of the user's location relative to any base station. This achieves a wide-area system with consistent characteristics. A user can take his equipment anywhere within the coverage area and get consistent accuracy results, without any intervention or intimate knowledge of GPS or DGPS.

c. Network operation. The OmniSTAR network consists of ten permanent base stations in the CONUS plus one in Mexico. These eleven stations track all GPS satellites above 5 degrees elevation and compute corrections every 600 milliseconds. The corrections are in RTCM SC-104, Version 2 message format. The corrections are then sent to the OmniSTAR Network Control Center (NCC) in Houston via wire networks. At the NCC these messages are checked, compressed, and formed into packets for transmission up to the OmniSTAR satellite transponder. This occurs approximately every few seconds. A packet will contain the latest corrections from each of the North American base stations. All OmniSTAR user sets receive these packets of data from the satellite transponder. The messages are first decoded and uncompressed. At that point, the message is an exact duplicate of the data as it was generated at each base station. Next, the atmospheric errors must be corrected as described below.

(1) Every base station automatically corrects for atmospheric errors at its location, because it is a part of the overall range error; but the user is likely not at any of those locations, so the corrections are not optimized for the user. Also, the OmniSTAR system has no information as to each individual's location. If these corrections are to be automatically optimized for each user's location, then it must be done in each user's OmniSTAR. For this reason, each OmniSTAR user set must be given an approximation of its location. The approximation only needs to be within several miles of its true position. Given that information, the OmniSTAR user set can use a model to compute and remove most of the atmospheric correction contained in satellite range corrections from each Base Station message, and substitute a correction for its own location. In spite of the loose approximation of the user's location, this information is crucial to the OmniSTAR process. It makes the operation totally automatic and it is necessary for sub-meter positioning. If it is totally ignored, errors of several meters can result.

(2) Fortunately, this requirement of giving the user's OmniSTAR an approximate location is easily solved. OmniSTAR is normally purchased as an integrated GPS/DGPS System, and the problem is taken care of automatically by using the position out of the GPS receiver as the approximation. It is wired internally to do exactly that.

(3) After the OmniSTAR processor has taken care of the atmospheric corrections, it then uses its location in an inverse distance-weighted least-squares solution. The output of that least-squares calculation is a synthesized RTCM SC-104 correction message that is optimized for the user's location. It is always optimized for the user's location that is input from the user's GPS receiver. This technique of optimizing the corrections for each user's location is called the "Virtual Base Station Solution." It is this technique that enables the OmniSTAR user to operate independently and consistently over the entire coverage area without regard to where he is in relation to the base stations.

(4) In most world areas, a single satellite is used by OmniSTAR to provide coverage over an entire continent--or at least very large geographic areas. In North America, a single satellite is used, but it needs three separate beams to cover the continent. The three beams are arranged to cover the East, Central, and Western portions of North America. The same data is broadcast over all three beams, but the user system must select the proper beam frequency. The beams have overlaps of several hundred miles, so the point where the frequency must be changed is not critical. Most recent models will search and select the strongest beam automatically, but older receivers must be manually set to the proper frequency. An approximation for the changeover from Eastern to the Central beam would be at a line from Detroit to New Orleans. The Central and Western Beams are divided at a line from Denver to El Paso. Again, these are approximations. All of the eastern Canadian Provinces, the Caribbean Islands, Central America (south of Mexico), and South America is covered by a single Satellite (AM-Sat). A single subscription service is available for all the areas covered by this satellite.

(5) OmniSTAR currently has several high-powered satellites in use around the world. They provide coverage for most of the world's land areas. Subscriptions are sold by geographic area. Any regional OmniSTAR Service Center can sell and activate subscriptions for any area. They may be arranged prior to traveling to a new area, or after arrival.

d. Equipment requirements. Several GPS manufacturers currently build models that combine OmniSTAR and GPS in one unit, using a common antenna. These are geodetic quality GPS receivers that have sub-meter capabilities. All are physically small and can be battery operated. They may be used in backpack applications or mounted in vehicles or aircraft. OmniSTAR typically provides the user with the GPS receiver equipment and subscription service for an annual lease fee.

e. STARFIX-Plus augmentation service. Fugro's STARFIX-Plus differential GPS augmentation system utilizes dual-frequency receivers at reference stations to more accurately model ionospheric activity within a survey region. It has application in distant offshore areas.

f. OmniSTAR URL contact. For additional details on the OmniSTAR system, contact www.omnistar.com

9-12. LandStar Differential GPS Service (Thales)

LandStar-DGPS operates similarly to OmniSTAR described above. It likewise is a satellite delivered, "fee-for-service" commercial DGPS correction service providing 24-hour real-time precise positioning in over 40 countries. LandStar operates a series of reference stations throughout the world that support the company's 24 hour manned control centers. LandStar-DGPS broadcasts correction data to users via the L-Band satellites. The system operates on a common global standard allowing LandStar receivers (and those that are compatible) to operate on any of the LandStar networks worldwide. Corrections are derived from a wide-area network solution similar to that described for OmniSTAR. This allows real-time positioning accuracies of one meter or less to be achieved throughout the LandStar coverage areas. A broad range of data receivers may be leased from Thales or from third-party vendors. LandStar-DGPS applications include survey and mapping, agriculture, natural resources, land management, utilities, pipeline transmission, engineering, land and air navigation and positioning. For additional information contact Thales LandStar at www.racal-landstar.com.

9-13. Code and Carrier Phase Wide Area Augmentation Services

A number of commercial subscription augmentation systems are now available that are designed to achieve sub-meter (and approaching decimeter) accuracy over wide areas by processing carrier phase observables. These systems have application in Corps navigation projects where real-time, decimeter-level vertical accuracy is required--e.g., water surface elevation measurement. These systems operate like the wide-area code systems described above, but are functionally similar to RTK systems. They involve multiple reference stations surrounding a project area, and adjust correctors at a central server to best model the remote receiver's location. The main difference is that more accurate phase measurements are observed at the reference stations and remote receiver, resulting in a more accurate real-time position. Fugro's STARFIX-HP (High Performance) service claims a short real-time initialization period and 10 to 20 centimeter accuracy a few hundred km from the reference station network. It is designed for a variety of offshore survey and geophysical applications, including dredging control. The Trimble Virtual Reference Station (VRS) operates similarly to the Fugro STARFIX-HP. It uses a cellular phone network to communicate between reference receivers and roving receivers. Code and carrier phase data from a network of fixed reference stations are processed in a central server where quality checks are performed, cycle slips are detected, and double difference solutions are computed. The central server communicates with the remote user in order to model the location of the rover. Final corrector data are then transmitted by cellular modem to the rover. Claimed accuracies for the VRS are at the centimeter-level for local topographic applications. A primary advantage of all these systems is redundancy achieved from using multiple reference stations to model the user's position, as opposed to having only a single reference station. Another advantage is the clear satellite or cellular communication link, as opposed to less reliable RF methods.

Section III: Conducting Differential GPS Carrier Phase Surveys

9-14. General

Differential (or relative) GPS carrier phase surveying is used to obtain the highest precision from GPS and has direct application to most USACE military construction and civil works engineering, topographic, photogrammetric, and construction surveying support functions.

a. Differential survey techniques. There are a variety of differential GPS surveying techniques used in the past or today. Some of the more common methods include:

- Static
- Kinematic
- Post-Processed Kinematic
- Pseudo-Kinematic
- Pseudo-Static
- Intermittent Static
- Stop and Go Kinematic
- Rapid Static Kinematic
- Fast Static Kinematic
- Continuous kinematic
- Real-Time Kinematic (RTK)
- Kinematic Ambiguity Resolution
- "On-the-Fly" Initialized Real-Time Kinematic

Some of the above methods are identical or performed similarly, with minor differences depending on the GPS receiver manufacturer. Procedurally, all these methods are similar in that each measures a 3-D baseline vector between a receiver at one point (usually of known local project coordinates) and a second receiver at another point, resulting in a vector difference between the two points occupied. The major distinction between static and kinematic baseline measurements involves the method by which the carrier wave integer cycle ambiguities are resolved; otherwise they are functionally the same process. General procedures for performing some of these methods are described in this section. However, manufacturer's recommended survey methods should be followed for conducting any GPS field survey.

b. Carrier phase data reduction. Most carrier phase surveying techniques, except OTF real-time kinematic (RTK) techniques, require post-processing of the observed data to determine the relative baseline vector differences. Post-processing of observed satellite data involves the differencing of signal phase measurements recorded by the receiver. The differencing process reduces biases in the receiver and satellite oscillators. It is also strongly recommended that all baseline reductions be performed in the field, if possible, in order to allow an on-site assessment of the survey adequacy.

9-15. Ambiguity Resolution

Cycle ambiguity is the unknown number of whole carrier wavelengths between the satellite and receiver, as was described in Chapter 5. Successful ambiguity resolution is required for baseline formulations. Generally, in static surveying, ambiguity resolution can be achieved through long-term averaging and simple geometrical calibration principles, resulting in solutions to a linear equation that produces a resultant position. Thus, 30 minutes or more of observations may be required to resolve the ambiguities in static surveys. A variety of physical and mathematical techniques have been developed to rapidly resolve the carrier phase ambiguities. The physical methods involve observations over known length baselines or equivalent known points. The most reliable method is to set the base and remote receivers up over known WGS 84 points, and collect data for at least 30 seconds. Initialization can also be accomplished over extremely short baselines, such as those shown in Figure 9-13. Another method that was more commonly used in the past was a reference-rover antenna swapping process. Most GPS systems today can automatically resolve ambiguities mathematically "on-the-fly" (OTF)--the technique used for many real-time kinematic (RTK) applications.

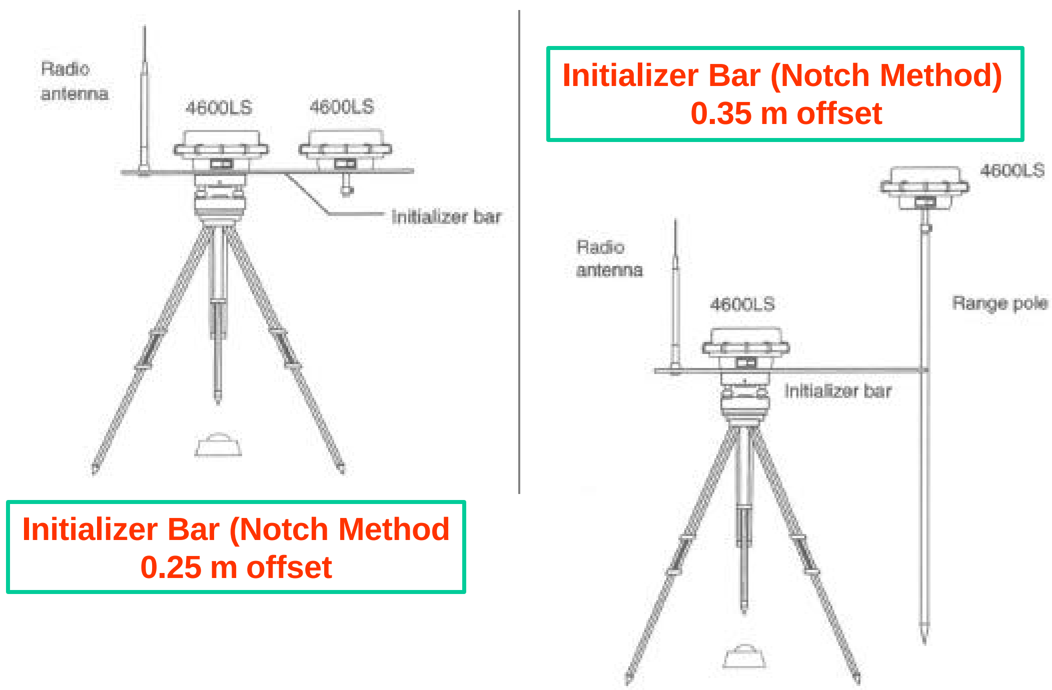


Figure 9-13. Ambiguity resolution of a Trimble 4600LS receiver using an Initializer Bar (Trimble Navigation, LTD)

9-16. Static Carrier Phase Field Survey Techniques

Static GPS surveying is perhaps the most common method of densifying project network control. Two GPS receivers are used to measure a GPS baseline distance. The line between a pair of GPS receivers from which simultaneous GPS data have been collected and processed is a vector referred to as a baseline. The station coordinate differences are calculated in terms of a 3-D, earth-centered coordinate system that utilizes X-, Y-, and Z-values based on the WGS 84 geocentric ellipsoid model. These coordinate differences are then subsequently shifted to fit the local project coordinate system.

a. General. GPS receiver pairs are set up over stations of either known or unknown location. Typically, one of the receivers is positioned over a point whose coordinates are known (or have been carried forward as on a traverse), and the second is positioned over another point whose coordinates are unknown, but are desired. Both GPS receivers must receive signals from the same four (or more) satellites for a period of time that can range from a few minutes to several hours, depending on the conditions of observation and precision required. Guidance for planning static occupation times for horizontal and vertical control surveys is covered in Chapter 8.

b. Satellite visibility requirements. The stations that are selected for GPS survey observations should have an unobstructed view of the sky of at least 15 degrees or greater above the horizon during the "observation window." An observation window is the period of time when observable satellites are in the sky and the survey can be successfully conducted.

c. Common satellite observations. It is critical for a static survey baseline reduction/solution that the receivers simultaneously observe the same satellites during the same time interval. For instance, if receiver No. 1 observes a satellite set during the time interval 1000 to 1200 and another receiver, receiver No. 2, observes that same satellite set during the time interval 1100 to 1300, only the period of common observation, 1100 to 1200, can be processed to formulate a correct vector difference between these receivers.

d. Data post-processing. After the observation session has been completed, the received GPS signals from both receivers are then processed (i.e. "post-processed") in a computer to calculate the 3-D baseline vector components between the two observed points. From these vector distances, local or geodetic coordinates may be computed and/or adjusted. This baseline reduction process is explained in Chapter 10.

e. Survey configuration. Static baselines may be extended from existing control using any of the control densification methods described in Chapter 8. These include networking, traverse, spur techniques, or combinations thereof. Specific requirements are normally contained in project instructions (or scopes of work) provided by the District office.

f. Receiver operation and data reduction. Specific receiver operation and baseline data post-processing requirements are very manufacturer dependent. The user is strongly advised to consult and study manufacturer's operations manuals thoroughly along with the baseline data reduction examples shown in this manual.

9-17. Rapid/Fast Static Field Surveying Procedures

Rapid or Fast Static surveying is a form of static surveying techniques. The rover or remote receiver spends only a short time on each unknown point, loss of lock is allowed while the rover traverses between points, and accuracies are similar to those of static survey methods. Observed rapid static data are post-processed. Rapid static surveys are normally performed over small project areas. The rapid static technique does require the use of dual-frequency (L1/L2) GPS receivers with either cross correlation or squaring (or other techniques) to compensate for A/S.

a. Survey procedure. Rapid static surveying requires that one receiver be placed over a known control point. A rover or remote receiver occupies each unknown station for 5-30 minutes, depending on the number of satellites and their geometry. Because most receiver operations are manufacturer specific, following the manufacturer's guidelines and procedures for this type of survey is important.

b. Rapid static data processing. Data collected in the rapid static mode should be post-processed in accordance with the manufacturer's specifications and software procedures.

c. Accuracy of rapid static surveys. Accuracies of rapid static surveys are similar to static surveys of a centimeter or less. This method can be used for medium to high accuracy surveys up to 1/100,000.

d. Typical field observation instructions. The following instructions for Trimble 4000 series receivers are representative of rapid (fast) static field survey observations. These procedures are used at the Corps' PROSPECT training course in Huntsville, AL.

Field Instructions on "FAST STATIC" GPS Data Collection
Survey IV PROSPECT Course

1 – Turn receiver on.
2 – After receiver boots-up, select MORE option using side keys (above **POWER** key)
3 – Select SETUP SURVEY CONTROLS
    3a – select MODIFY FAST STATIC CONTROLS
        3b – set elevation mask to 15 degrees
        3c – set minimum meas times to 5 min for each
        3d – set meas sync time to 10 sec
        3e – select accept using side keys
4 – Press **STATUS** key to check # of satellites
5 – Press **LOG DATA** key
6 – Select START FAST STATIC OR KINEMATIC SURVEY using side keys
7 – Select START FAST STATIC SURVEY using side keys
8 – Once antenna is set-up and plumbed over point, select START using side keys
9 – Enter mark id using key pad and side keys (usually first four letters of the station name) and press **ENTER** key
10 – Select INPUT/CHNGS from side keys
    10a – select CHANGES using side keys
        10b – select ANTENNA HEIGHT using side keys
            10c – enter antenna height (if fixed height pole is being used at the reference and remote, enter 2.069 meters and select MEAS TYPE as **<u>true vertical</u>**) and press ACCEPT using side keys
        10d – select FILE NAME using side keys
            10e – enter file name (i.e. ROV1 or COE1…) and make sure session # is correct, (last # in file name) and select ACCEPT. (This is only done once during a survey at both the reference and remote stations)
        10f – press **CLEAR** or **LOG DATA** key to get back to fast static menu
11 – **If at reference station, nothing needs to be done**, read a good book until rover unit returns. You might however, press the **STATUS** key and then press MORE twice (using the side keys) to make sure data is being logged. Pressing the **LOG DATA** button will return you to the fast static menu.
12 – **If at rover station**, fill out field form, wait until the screen time is 0 and says press MOVE before moving. **(<u>do not disconnect power or turn receiver off when moving</u>)**
    12a – press MOVE using the side keys
    12b – now move to next mark, satellite lock does not have to be maintained in-between stations
    12c – once plumb at next mark, press START
    12d – enter new mark id (just change 1st 4 characters) and press **ENTER** key.
    Repeat step 12 until finished with survey.
13 – Pressing the **STATUS** key will give you UTC time. Then, pressing MORE twice (using the side keys) will show if data is being logged on each satellite. Pressing the **LOG DATA** button will return you to the fast static menu.
14 – Once finished with survey, select END SURVEY using side keys, select YES and check antenna height and accept if correct.
15 – To turn off, hold **POWER** key in until screen goes out.

9-18. Kinematic GPS Field Survey Techniques

Kinematic surveying using differential carrier phase tracking is similar to static carrier phase methods because it also requires two receivers recording observations simultaneously. The reference receiver remains fixed on a known control point while the roving receiver collects data on a constantly moving platform (vehicle, vessel, aircraft, manpack, etc.), as illustrated in Figure 9-14. The observation data is later post-processed to calculate relative vector/coordinate differences to the roving receiver. A kinematic survey requires, at minimum, two GPS receivers. One receiver is set over a known point (reference station) and the other is used as a rover (i.e. moved from point to point or along a path). Before the rover receiver can collect positional data at an unknown point, a period of static initialization may be required. (Alternatively, an OTF initialization technique may be used, as described below). This period of initialization is dependent on the number of visible satellites. Once initialization is completed, the rover receiver can move from point to point as long as satellite lock is maintained. If loss of satellite lock occurs, a new period of static initialization may be required. Some of the field techniques for the more common types of kinematic GPS surveying are described below. More detailed field procedures are found in operator's manuals provided by the GPS receiver manufacturer.

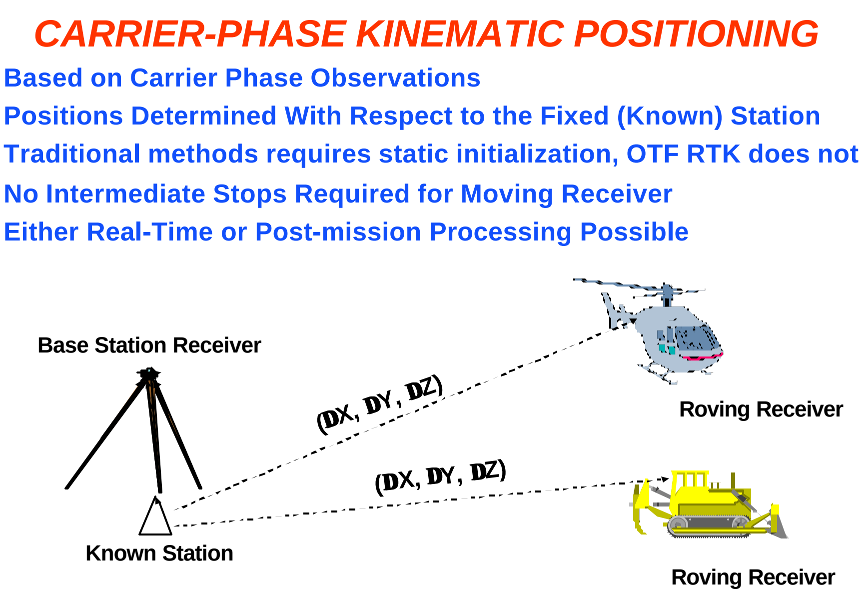


Figure 9-14. Kinematic survey techniques

9-19. Stop-and-Go Kinematic Field Survey Techniques

Differential GPS surveying known as "stop-and-go" is typically used for setting accurate topographic mapping or construction control points. It is similar to static surveying methods in that each method requires at least two receivers simultaneously recording observations. Unlike static methods, an initial calibration process is required prior to conducting the survey. A major difference between static and stop-and-go surveying is the amount of time required for a roving receiver to stay fixed over a point of unknown position. In stop-and-go surveying, the first receiver--the base station or reference receiver--remains fixed on a known control point. The second receiver--the "rover" receiver--collects observations statically on a point of unknown position for a period of time (usually a few minutes), and then moves to subsequent unknown points to collect data for a short period of time. During the survey, at least four common satellites (preferably five) need to be continuously tracked by both receivers. Once the rover receiver has occupied all required points, the observations are then post-processed to calculate baseline vector/coordinate differences between the known control point and points occupied by the rover receiver during the survey session. The main advantage of this form of GPS surveying over static surveying is the reduced occupation time required over the unknown points. Stop-and-go kinematic surveying requires less occupation time over unknown points than static methods. Therefore, time and cost for the conduct of a survey are significantly reduced. Achievable accuracies typically equal or exceed 10 mm.

a. Survey procedure. Stop-and-go surveying is performed similarly to a conventional electronic total station radial survey. The system is initially calibrated by performing either an antenna swap with one known point and one unknown point, by performing a static measurement over a known baseline, or by observing static data at another known point on the network. This calibration process is performed to resolve carrier phase cycle ambiguities. A known baseline may be part of the existing network or can be established using static GPS survey procedures described above. The roving receiver then traverses between unknown points as if performing a radial topographic survey. Typically, the points are double-connected, or double-run, as in a level line. Optionally, two fixed receivers may be used to provide redundancy on the remote points. With only a few minutes of data collection at a point, topographic X-Y-Z coordinate production is high.

b. Satellite lock. During a stop-and-go survey, the rover receiver must maintain lock on at least 4 satellites during the period of survey. The reference station must also be observing at least the same 4 satellites. Loss of lock occurs when the receiver is unable to continuously record satellite signals or the transmitted satellite signal is disrupted and the receiver is not able to record it. If satellite lock is lost, the roving receiver must reobserve the last fixed point surveyed before loss of lock. The operator must closely monitor the GPS receiver when performing the stop-and-go survey to ensure loss of lock does not occur. Some manufacturers have now incorporated an alarm into their receiver that warns the user when loss of lock occurs, thus making the operator's job of monitoring the receiver easier.

c. Site constraints. Survey site selection and the route between points to be surveyed are critical. All observing points must have a clear view of satellites having a vertical angle of 15 degrees or greater. The routes between rover occupation points must be clear of obstructions so that the satellite signal is not interrupted. Each unknown station to be occupied should be observed for a minimum of at least 90 seconds. Remote points should be occupied two or three times to provide redundancy between observations.

d. Antenna swap calibration procedure. The antenna swap initialization procedure requires that two nearby points be occupied and that both points maintain an unobstructed view of the horizon. A minimum of four satellites and constant lock are required; however, more than four satellites are preferred. To perform an antenna swap, one receiver/antenna is placed over a point of known control and the second, a distance of 10 to 100 m away from the other receiver. The receivers at each station collect data for approximately 2 to 4 minutes. The receivers/antennae sets then swap locations: the receiver/antenna at the known station is moved to the unknown site while the other receiver/antenna at the unknown site is moved to the known site. Satellite data are again collected for 2 to 4 minutes. The receivers are then swapped back to their original locations. This completes one antenna swap calibration. If satellite lock is lost during the process, the calibration procedure must be repeated. The baseline data are processed to determine and eliminate the carrier integer ambiguity. Although an antenna swap procedure is used to initialize a stop-and-go survey, the same technique can also be used to determine a precise baseline and azimuth between two points.

e. Accuracy of stop-and-go surveys. Accuracy of stop-and-go baseline measurements will well exceed 1 part in 5,000; thus, supplemental project/mapping horizontal control can be established using this technique. For many USACE projects, this order of horizontal accuracy will be more than adequate; however, field procedures should be designed to provide adequate redundancy for what are basically "open-ended" or "spur" points. Good satellite geometry and minimum multipath are also essential in performing acceptable stop-and-go surveys.

9-20. Pseudo-Kinematic Field Survey Techniques

Pseudo-kinematic GPS surveying is similar to stop-and-go kinematic techniques except that loss of satellite lock is tolerated when the receiver is transported between occupation sites (in fact, the roving receiver can be turned off during movement between occupation sites, although this is not recommended). This feature provides the surveyor with a more favorable positioning technique since obstructions such as bridge overpasses, tall buildings, and overhanging vegetation are common. Loss of lock that may result due to these obstructions is more tolerable when pseudo-kinematic techniques are employed.

a. General. The pseudo-kinematic technique requires that one receiver be placed over a known control station. A rover receiver occupies each unknown point or monument for 5-10 minutes. Approximately 1 hour (but not longer than 4 hours) after the initial occupation, the same rover receiver must reoccupy each unknown point.

b. Common satellite requirements. The pseudo-kinematic technique requires that at least four of the same satellites be observed between initial unknown point occupations and the requisite reoccupations. For example, the rover receiver occupies Station A for the first 5 minutes and tracks satellites 6, 9, 11, 12, 13; then 1 hour later, during the second occupation of Station A, the rover receiver tracks satellites 2, 6, 8, 9, 19. In this example, only satellites 6 and 9 are common to the two sets, so the data cannot be processed because four common satellites were not tracked for the initial station occupation and the requisite reoccupation.

c. Planning. Prior mission planning is essential in conducting a successful pseudo-kinematic survey. Especially critical is the determination of whether or not common satellite coverage will be present for the desired period of the survey. Also, during the period of observation, one receiver, the base receiver, must continuously occupy a known control station.

d. Pseudo-kinematic data processing. Pseudo-kinematic survey satellite data records and resultant baseline processing methods are similar to those performed for static GPS surveys. Since the pseudo-kinematic technique requires each station to be occupied for 5 minutes and then reoccupied for 5 minutes approximately an hour later, this technique is not suitable when control stations are widely spaced and transportation between stations within the allotted time is impractical.

e. Accuracy of pseudo-kinematic surveys. Pseudo-kinematic survey accuracies are at the centimeter level.

9-21. Real-Time Kinematic (RTK) Field Surveying Techniques

Unlike the static and kinematic methods previously covered, RTK methods provide real-time positioning results. Real-time surveys are most useful for construction stakeout, setting project control, and topographic mapping. To obtain real-time coordinates, a communication link (radio or satellite) is required between the reference base station and the roving receiver. RTK surveying is similar to other kinematic GPS survey methods in that it requires two receivers simultaneously recording observations. Unlike other GPS methods, the rover receiver can be continuously moving. RTK surveys require dual-frequency (L1/L2) GPS observations. Periodic losses of satellite lock can also be tolerated. Since RTK uses the L2 frequency, the GPS receiver must be capable of tracking the L2 frequency during A/S. There are several techniques used to obtain L2 during A/S. These include squaring and cross correlation methods.

Figure 9-15. Real-Time kinematic survey reference and remote stations

a. Ambiguity resolution. As previously explained, carrier phase integer ambiguity resolution is required for successful baseline formulations. RTK surveys can be initialized using the methods previously described--e.g., at a known point. However, if the receiver is equipped with "on-the-fly" (OTF) initialization technology, then the remote can initialize and resolve integers without a period of static initialization. With OTF capability, if loss of satellite lock occurs, initialization can occur while in motion. OTF integers can usually be resolved at the rover within 10-30 seconds, depending on the distance from the reference station. This initialization is automatically performed by the survey controller device. OTF makes use of the L2 frequency in resolving the integer ambiguity. At least 5 satellites are required for OTF initialization, and after initialization, at least 4 satellites must be tracked. After the integers are resolved, only the L1 C/A is used compute the positions. If no OTF capability is available, then initialization should be made at a known point and 4 satellites must be kept in view at all times--loss of lock requires reinitialization.

b. Survey procedure. RTK/OTF surveying requires dual-frequency L1/L2 GPS receivers. One of the GPS receivers is set over a known point and the other is placed on a moving or roving platform. The survey controller will determine the amount of time required to lock in over each remote point. If the survey is performed in real-time, a data link and a processor (external or internal) are needed. The data link is used to transfer the raw data from the reference station to the remote. If the radio link is lost, then post-processing techniques are available to compute the survey--e.g., Trimble's "Infill" option.

c. Accuracy of RTK surveys. RTK surveys are accurate to within 3-10 cm (in 3-D) when the distance from the reference to the rover does not exceed 10 k.

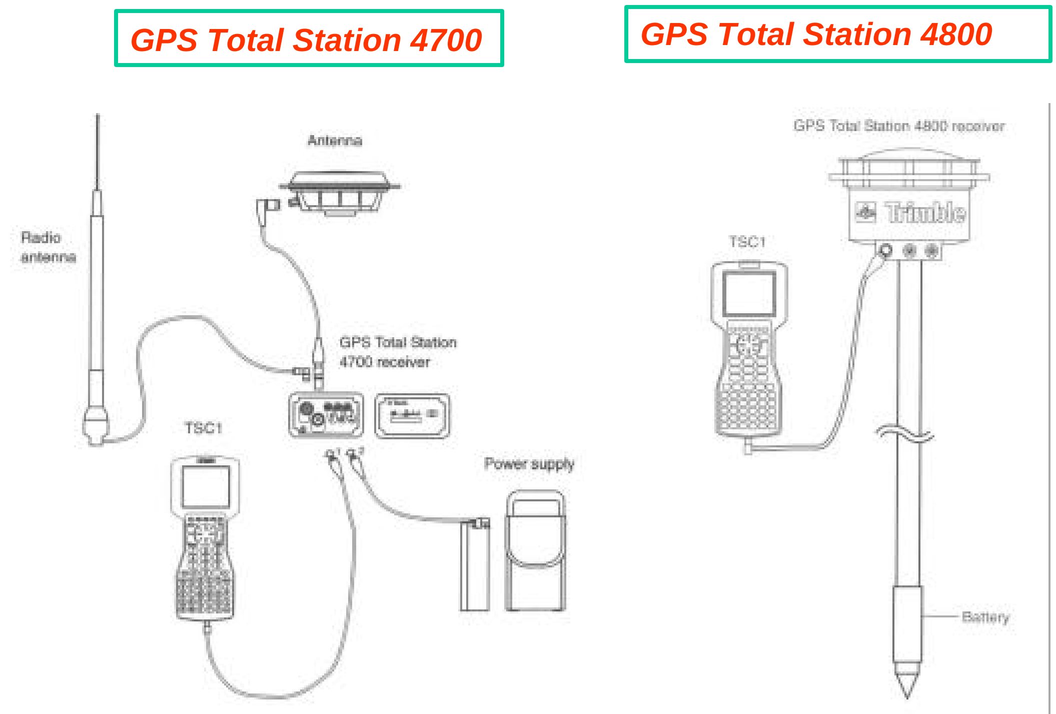


Figure 9-16. Rover GPS receiver setup for RTK surveys--Trimble GPS Total Station 4700 and Trimble GPS Total Station 4800. (Trimble Navigation LTD)

9-22. RTK Survey Field Procedures and Calibrations

The USFS and BLM *Standards and Guidelines for Cadastral Surveys* (USFS/BLM 2001) contains guidance for performing RTK surveys that is directly applicable to USACE RTK topographic mapping and construction control surveys. Some of the more significant field procedures recommended by the USFS/BLM are outlined below. These generally reduce down to (1) system checks, (2) measurement procedures, (3) and calibrations.

a. RTK system check. A RTK system check shall be made prior to any measurements. RTK system checks may also be made at any time during the course of each RTK survey session or at any time the base receiver(s) and rover receiver(s) are set up and initialized per the manufacturer's recommended procedures. This check is a measurement from the RTK base setup to another known project control monument. The resulting observed position is then compared by inverse to the previously observed position for the known point. This inverse should be within the manufacturer's recommended values for duplicate point tolerance measurements--typically within ± 2.5 cm in position and within ± 5 cm in elevation. This RTK system check is designed to check the following system parameters:

- The correct reference base station is occupied.
- The GPS antenna height is correctly measured and entered at the base and rover.
- The receiver antennas are plumb over station at base and rover.
- The base coordinates are in the correct datum and plane projections are correct.
- The reference base stations or the remote stations have not been disturbed.
- The radio-communication link is working.
- The RTK system is initialized correctly.
- RMS values are within manufacturer's limits.

b. RTK measurements. RTK topographic observations are usually made using one or more base stations and one or more rover receivers. RTK measurements shall be made after the system setup check procedures have been completed. Use manufacturer's recommended observation times for the highest level of accuracy when setting mapping or construction control points, for example, 180 seconds of time or when the horizontal (e.g., 2 cm) and vertical (e.g., 5 cm) precision has been met for a kinematic control point. Under optimal conditions a deviation from the manufacturer's suggested time is appropriate; for example, a point may be observed using 30 seconds of time and 20 epochs of measurement data. However, observation times should be set to account for field conditions, measurement methods (i.e. Trimble "topo point" or "kinematic control point") and the type of measurement checks being performed.

c. Recommended methods for setting control points using RTK. One method is to observe the unknown point two or more times with the same point name (e.g., 100700) and use a duplicate point tolerance measurement criteria of 2.5 cm. When observing these measurements, the antenna shall be inverted and the receiver reinitialized between observations. Another method is to observe two separate baselines (M1 and M2) to the unknown point. The baseline data are stored to the data collector or receiver for a specified number of seconds or epochs to meet a specified level of precision recommended by the manufacturer for a kinematic control point. Observation time may be increased due to the constraints of on-the-fly (OTF) post-processing kinematic (i.e. 200+ sec) if the field data is post-processed as a check. Between the M1 and M2 baseline measurements the antenna should be inverted to force a loss of satellite lock, which forces the system to reinitialize. The point values resulting from the first baseline measurement are stored and labeled (e.g., 100700M1), and the point values resulting from the second baseline measurement are stored and labeled (e.g., 100700M2). A field check of the level of accuracy between the measurements may be done by an inverse between M1 and M2. The resulting inverse distances should agree within 2.5 cm.

d. Typical field observation instructions. The following instructions for Trimble 4000 series receivers are representative of RTK/OTF static field survey observations. These procedures are used at the Corps' PROSPECT training course in Huntsville, AL (see also Figure 9-17).

Instructions on "Real-Time Kinematic" GPS Data Collection

1 – Turn receiver on
2 – While receiver boots-up, you may need to select **CLEAR** key
3 – Press **CONTROL** key
    3a – select Rover Control
        Enable L1/L2 and press ENTER
    3b – select Power Control
        select Power output ENABLED and press ENTER
4 – Press **STATUS** key to check # of satellites
    4a – select **POSITION** to check for (RTK-moving/Fix/L1)

Move to first occupation station

5 – Press **LOG DATA** key
6 – Select START FAST STATIC OR KINEMATIC SURVEY using side keys
7 – Select START KINEMATIC SURVEY using side keys
8 – Once antenna is set-up and plumbed over point
    8a – enter POINT ID using keypad and side keys

MH	for Manhole
LP	for Lightpole
DG	for Drainage Grate
SE	for Spot elevation
TC	for Top of Curb
BEVX	for BEV check point (X=1-6)
COEX	for COE check point (X=1-3)

    8b – to set or change HI or FILENAME, Select **INPUT/CHNGS** from side keys
        8b1 – select **CHANGES** using side keys
            for antenna height, select **ANTENNA HEIGHT** using side keys
            check/enter antenna height and MEAS TYPE and then press
            ACCEPT and then CLEAR

            For filename, select **FILENAME** using side keys
            Enter filename (ONLY need to change this ONCE for entire
            session) and then press ACCEPT and then CLEAR

    8c – select STATIC using side keys
    8d – observe STATIC WAIT until ROVE appears in upper right
    8e – wait until EPOCHS reaches 10 and then press ROVE
    8f – move to next occupation station
9 – Repeat step 8 until done collecting occupations
10 – When completed, press **LOG DATA**
    10a – select **END SURVEY** using side keys, select YES and check antenna height
    and press ACCEPT

11 – To turn off, hold **POWER** key in until screen goes out.

Figure 9-17. RTK positioning of drainage basin at Huntsville, AL Tom Bevill Center (PROSPECT GPS Training Course--2002)